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AGRICULTURAL MEMORANDUM NO 1020

THE USE OF 'CRITICAL' WEATHER PERIODS IN THE PREDICTION OF POTATO BLIGHT OUTBREAKS
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SUMMARY

Published data on the progress of potato blight during the early stages of an epidemic are used to develop a scheme for the accumulation of 'critical' periods to predict the date of the first 'outbreak' in an area. The performance of the Smith period (Smith 1956) and a newly defined critical period* (Sparks 1984) are compared for stations in East Anglia from 1978 to 1983.

INTRODUCTION

It is generally agreed that epidemics of potato blight start either on dumps or, more often, from diseased tubers in the fields. A small proportion of such tubers produce plants with stem lesions above the ground and can give rise to primary foci of the disease. The number of primary foci and the fields that contain them are generally unknown and are likely to be variable from year to year. Furthermore, it is the microclimate in only those fields that contain primary foci that determines the course of the early stages of the epidemic and the timing of the spread of the fungus to crops lacking initial sources. (Hirst & Stedman 1960)

There is much evidence (Hirst 1955, Uhlig 1955, Clayson & Robertson 1957, etc) to show that about 3 generations of blight are required for the disease to progress from the first few invaded stems to the outbreak level of 0.1 per cent on the BMS scale.

Since we cannot know which fields contains diseased stems, or when the lesions first appear above ground in each field, we cannot expect to predict with complete accuracy the date of the first 'outbreak'. Nevertheless, a good relationship between weather and disease progress, and representative weather observations, should allow the calculation of the earliest possible outbreak date and the prediction of the most probable time of the first outbreak.

TREATMENT OF CRITICAL PERIODS IN THE EARLY STAGES OF A BLIGHT EPIDEMIC

The first investigators of the relationship between weather and potato blight sought to define a set of conditions which, when they occurred, would invariably be followed by an outbreak of blight within about 2 weeks. They found that, with the best criteria they could devise, there were a number of favourable days that were not followed by blight outbreaks within 15 days and a few favourable days that were not followed by blight within 30 days (Wiltshire 1931). Unaware, presumably, of the way blight develops from primary foci they regarded such "false" warnings as an indication that their criteria were defective.

To overcome this problem Beaumont suggested that for each district there would be a time in the season before which his critical periods would not be followed by outbreaks of blight. In the early operational use of Beaumont periods Large employed this concept of a "zero date" even though he was well aware of the importance of early blight periods. He says (Large 1956) "This working rule does not by any means imply that the June flushes, which occur every year, are of no significance in the origin of epidemics. They almost certainly play a part in awakening blight on the

*See Appendix 1 for definitions

widely scattered, and probably very few, plants having shoots infected from over-wintering blight in the tubers".

Some meteorologists, notably Bourke (1955) and Smith (1974) attempted to take account of early season blight periods by accumulating the number of hours in critical periods and suggesting that the outbreak should be seen after a given number of such hours. These attempts were not very successful, partly because they used prediction rules that took little or no account of the ability of the fungus to spread at temperatures below 10°C and partly because they took no account of the development of separate generations of blight.

MULTIPLICATIVE GENERATIONS OF BLIGHT

A new infection period produces a multiplicative generation of disease only if the majority of lesions produced by a previous infection period are capable of producing spores at the time of the new infection period. Therefore, infection periods that are very close together or those that are a long time apart do not result in multiplicative generations.

The importance of multiplicative generations can be illustrated by a simple example. Assume that blight periods occur on 1 and 3 July and that each produces 10 new infections for each lesion active at the time of the critical period. By 20 July there will be about 20 times the number of lesions active on 1 July; 10 produced by the first blight period and 10 produced by the second. Compare that with the results of 2 similar periods occurring on 1 and 10 July. By the 10 July the infections produced on 1 July will have developed into lesions and each of those will produce 10 new infections as a result of the second blight period so that the total number of lesions present by 20 July will be $10 + 10 \times 10 = 110$ times the number on the 1 July; that is more than 5 times the number produced by the 2 closely spaced periods. The identification of multiplicative generations of blight is, therefore, very important in the prediction of its progress.

The time from infection to the appearance of lesions is dependent on temperature (Crosier 1934), the age of the plant, the position of the infection and the concentration of sporangia (Warren et al 1971) and of course the variety. At high temperatures with a high concentration of sporangia on a susceptible leaf a lesion may appear after only 3 days while with the opposite conditions up to 21 days may be required.

Once lesions have formed their rate of expansion depends mainly on temperature (Crosier 1934) and variety (Lapwood 1961a). Lapwood (1961b) found that the time for the fungus to destroy 50% of leaflets of inoculated leaves varied from about 10 to 20 days.

It is clear from the results quoted above that no simple rule can determine with complete accuracy when an infection period will result in a multiplicative generation and when it will merely add to an existing generation but some guidance can be given. At the temperatures that prevail before July in the British Isles critical periods less than 5 days apart cannot result in a new multiplicative generation while those between 8 and 22 days apart almost certainly do. The rate of decline in the number of active lesions more than 22 days after the infection period that produced them is uncertain but it is probable that relatively few remain active after 28 days. These considerations suggest the following relationship between the separation between critical periods and their contribution to the number of multiplicative generations:-

Interval between critical periods (days)	0-4	5-7	8-22	23-28	> 28
Contribution to the number of multiplicative generations	0	$\frac{1}{2}$	1	$\frac{1}{2}$	0

The above table can give no more than a rough guide to the effective number of generations of blight and it is sometimes difficult to apply objectively, nevertheless, it will be shown that a simple count of possible generations of blight can give useful guidance on the date of the first blight outbreak.

THE PERFORMANCE OF SMITH PERIODS 1978-1983

Figure 1 shows the Smith Periods and $\frac{1}{2}$ Smith Periods recorded at 9 stations in the Eastern Region during the years 1978 to 1983. The figure gives correctly the general impression of the severity of blight in the individual years. There are for example few flushes of Smith Periods in 1979 which was a relatively blight free year. It is not, however, possible to estimate the date of first outbreak in maincrops with any confidence from the chart. If the normal "zero date" towards the end of June is assumed the outbreaks in 1979, 1981 and 1983 are not predicted while if a "zero date" at the end of May is assumed so that the outbreak in 1981 is correctly predicted then there are premature predictions in 1980 and 1982 but the outbreak in 1983 is still not predicted.

An attempt to use Smith Periods more quantitatively was made by counting the number of periods between the 15 April and 5 days before the first outbreak each year and the number of multiplicative generations of blight permitted by Smith Periods each year before the outbreak. The results, shown in Table 1, are not encouraging. There is no way of reconciling a total of 45 Smith Periods and 12 generations at the 9 stations before the outbreak in 1980 with only 1 Smith Period before the outbreak in 1983. This is not unexpected because Smith Periods and Beaumont Periods before them were designed to eliminate as many as possible of the early season "false" warnings and, therefore, cannot be expected to perform well in a prediction scheme that attempts to total such warnings.

THE PERFORMANCE OF THE NEW CRITICAL PERIODS 1978-1983

Figure 2 shows blight periods calculated using the new warning system at 9 stations in Eastern Region during 1978-1983 (the data for Heathrow should be ignored in this discussion). The chart correctly gives the general impression that 1979 was a less severe blight year than the other 5 and also suggests that there may be a fairly equal number of blight periods each year before the first outbreak. Table 2 shows the counts of blight periods and possible multiplicative generations of blight between 15 April and 5 days before the first outbreak each year. Numbers of critical periods are variable but possible generations are similar in all years except in 1979 when they are much lower than in the other 5 years. Table 3 shows the number of possible multiplicative generations at the individual stations each year and it can be seen that in all years there were at least 3 generations at at least 1 station before the first blight outbreak was reported. This lends some support to the idea that 3 generations of the disease are required before the first outbreak but does not necessarily allow the outbreak to be predicted because in 2 of the years there were 4 generations at 1 station and the date of the 3rd generation may have given a premature warning. To check that possibility the date of the critical period that gave rise to the 3rd multiplicative generation was noted and is listed in Table 4 with the date of the first reported outbreak. The mean difference between the date of the start of the 3rd generation and the date of the first reported outbreak is $13\frac{1}{2}$ days with a standard deviation of 4.2 days. The correlation coefficient between the dates is 0.98 which is significant even with only 6 years data.

DISCUSSION

Beaumont and Smith Periods were designed to eliminate, as far as possible, "false" early season warnings. This was achieved by discounting any humid periods during which the temperature fell below 10°C . Not all premature warnings are eliminated in that way and in the operational use of both Beaumont and Smith Periods a "zero date" before which the periods are not considered effective has frequently been used. This procedure has worked well in most years but it could not succeed in years like 1981 and 1983 when the outbreaks in the Eastern Region were before the normal zero date.

To overcome these problems an attempt has been made to define a new blight period that identifies every opportunity for the fungus to progress early in the season and to predict the progress of the disease from the invasion of the first few stems to 'outbreak'.

This approach shows considerable promise but it is not likely to perform as well in all parts of the country and in all years as it has in Eastern Region during the period 1978-1983. Even there it almost failed in 1979 when a correct 'prediction' depended on a single blight period at a single station - not a circumstance that would give a plant pathologist much confidence before the event! Even if the blight risk criteria are correct the problem of the lack of representivity of the weather observations remains.

Attempting to take account of the development of blight from the emergence of the first stem lesions does not completely remove the need for a 'zero' date because only those blight periods occurring after the emergence of the first lesions above ground are significant. Hirst and Steadman (1960) who planted many diseased tubers and examined the resulting plants for stem lesions say "In years when the first symptom was found in May or by mid June (1954, 1956 and 1958) there was or had recently been a cool dull week with an inch of rain. In 1957 the first invaded stems were not found until mid-July; the first week during the season when the above condition applied". Unfortunately this rule did not give correct predictions in 1955 when no invaded stems were found nor in 1959 when the first stem lesion was found about a month after the first dull wet week. There is, however, some support from the events of recent years for the idea that dull wet weather in spring is conducive to an early outbreak of blight and, by implication, the early appearance of stem lesions above ground. The total rainfall in East Anglia during April and May was higher in 1981 than in any previous year since before 1954 and the April and May rainfall in 1983 was the highest on record for many stations in the region. The year with the 3rd highest rainfall in April and May since before 1954 was 1979 and in that year there was an early outbreak of blight inspite of relatively few early critical periods. These data suggest that a very wet spring increases the risk of an early outbreak of blight but further work would be needed to determine whether it is necessary to take rainfall into account explicitly or whether it is sufficient to accumulate possible multiplicative generations of blight from the date of emergence of the plants.

The emphasis in this paper has been on the prediction of early outbreaks of blight and the new critical periods are designed to assess the possibility of blight development in an open crop early in the season. They may slightly underestimate the risk to a crop that has met within the row and will considerably underestimate the risk to a crop that has met across the rows.

CONCLUSIONS

A newly defined critical period for blight development together with a count of the possible multiplicative generations of the disease may allow more accurate predictions of the date of the first blight outbreak than has been possible using Smith or Beaumont periods. The new system would have worked well for maincrop potatoes in East Anglia from 1978 to 1983 and should be tested in other potato growing areas and for early potatoes.

Any comments on this paper should be sent to the author.

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March 1984

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TABLE 1 - ANALYSIS OF SMITH PERIODS AT 9 STATIONS IN EAST ANGLIA
FROM 15 APRIL TO 5 DAYS BEFORE THE FIRST REPORTED OUTBREAK

YEAR	TOTAL NUMBER OF PERIODS	TOTAL NUMBER OF POSSIBLE MULTIPLICATIVE GENERATIONS
1978	12*	3½*
1979	14	2
1980	45	12
1981	18	5
1982	42	8
1983	1	0

*There were reports from only 7 stations.

TABLE 2 - ANALYSIS OF NEW CRITICAL PERIODS AT 9 STATIONS IN EAST ANGLIA
FROM 15 APRIL TO 5 DAYS BEFORE THE FIRST REPORTED OUTBREAK

YEAR	TOTAL NUMBER OF PERIODS	TOTAL NUMBER OF POSSIBLE MULTIPLICATIVE GENERATIONS
1978	62*	14½*
1979	28	7½
1980	64	16½
1981	41	16
1982	54	15½
1983	37	14½

*There were reports from only 7 stations.

TABLE 3 - PERFORMANCE OF THE NEW BLIGHT PREDICTION SCHEME 1978-1983

NUMBER OF POSSIBLE MULTIPLICATIVE GENERATIONS BETWEEN 15 APRIL AND 5 DAYS
BEFORE FIRST REPORTED OUTBREAK

STATION/YEAR	1978	1979	1980	1981	1982	1983
377 WAD	2½	1½	2	1	1½	0
391 CON	-	0	1½	1	1½	1½
482 MAR	2½	0	3	2	2½	1
495 COL	½	0	1½	0	0	1
496 HEM	-	1	1½	3	3	3
566 WYT	2	0	2	1	4	1½
586 HON	2	3	1	2	½	2
590 WAT	4	0	1	3½	2	1½
683 STA	1	2	3	2½	½	3
TOTAL	14½	7½	16½	16	15½	14½

TABLE 4 - DATES OF FIRST REPORTED OUTBREAKS IN MAINCROPS IN EASTERN REGION
AND DATES OF CRITICAL PERIODS ALLOWING THE THIRD MULTIPLICATIVE GENERATION
OF BLIGHT

YEAR	DATE OF FIRST REPORTED OUTBREAK	EARLIEST DATE OF A POSSIBLE THIRD MULTIPLICATIVE GENERATION AT ANY STATION IN THE REGION
1978	18 JUL	4 JUL
1979	4 JUL	14 JUN
1980	25 JUL	18 JUL
1981	8 JUN	26 MAY
1982	28 JUN	16 JUN
1983	13 JUN	29 MAY

A Smith Period is two consecutive days each with:-

- a) Minimum temperature 10°C or above.
b) Duration of humidity of 90 per cent or above : at least 11 hours.

A "near miss" is two days of 10 hours of such high humidity.

The New Critical Period (Sparks 1984)

The new critical period consists of a period of high humidity in the crop for spore production followed by periods suitable for spore survival, germination and infection.

Spores grow during a humid period, that is a period with rain, hail, drizzle or fog OR with the dew-point depression in the crop $\leq 1.6^{\circ}\text{C}$. If H is the number of hours in the humid period and T is the average temperature of the humid period then the index of spore production (SP) is given by:-

$$\begin{aligned} \text{SP} &= 3 \text{ if } H \geq 1/(0.00562 * T - 0.0298) \\ \text{SP} &= 2 \text{ if } H \geq 1/(0.006734 * T - 0.030303) \\ \text{SP} &= 1 \text{ if } H \geq 1/(0.00787 * T - 0.0167) \end{aligned}$$

else SP = 0

Spore survival (SS) is estimated using the number of hours from 0600 to 1700 GMT with dew-point depression in the crop (DPD) more than 4°C.

SS	=	3	if number of hours with DPD	>	4	=	0 or 1
SS	=	2	" " " " " "	>	"	=	2 to 4
SS	=	1	" " " " " "	>	"	=	5 to 8
SS	=	0	" " " " " "	>	"	=	9 to 12

For optimum germination and infection there must be a humid period after 1700.

There is a critical period if $SP * SS \geq 3$ and a humid period after 1700 or $SP * SS \geq 6$ with no humid period after 1700.

Figure 1 POTATO BLIGHT PREDICTION SCHEME (SMITH) 1978-1983

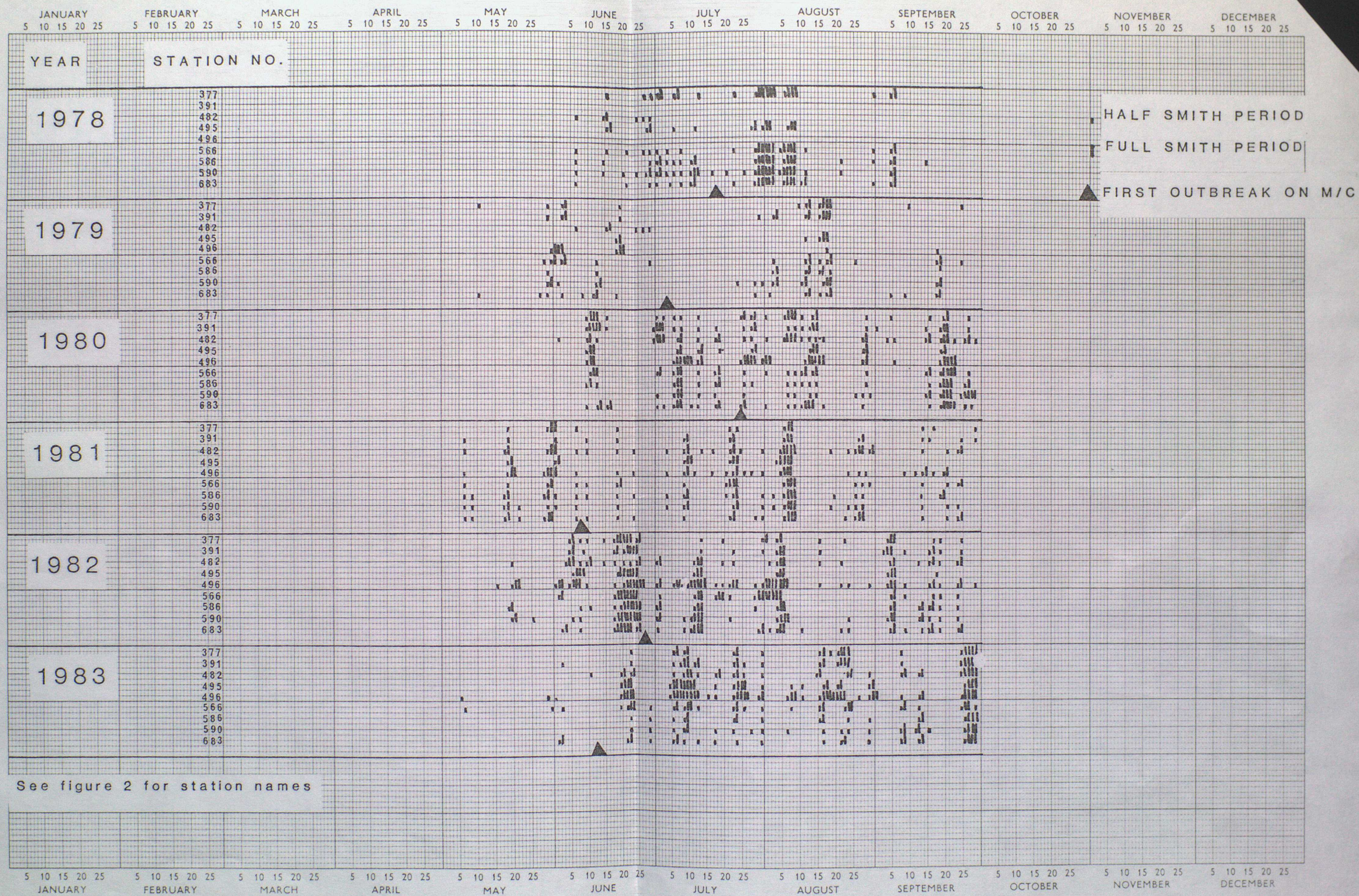


Figure 2 POTATO BLIGHT PREDICTION SCHEME (SPARKS) 1978-1983

